Parameterization of Cumulus Convective Cloud Systems in Mesoscale Forecast Models

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LONG-TERM GOALS

The development and improvement of the microphysics parameterization of cumulus convective clouds in mesoscale numerical weather prediction models

OBJECTIVES

Conduct detailed studies of cloud microphysical processes in order to develop a unified parameterization of boundary layer stratocumulus and trade wind cumulus convective clouds. Develop a parameterization of subgrid cloud variability that in combination with the unified parameterization of conversion/sedimentation rates will provide a complete formulation of microphysical processes in convective clouds for use in mesoscale forecast models. Test the parameterization using COAMPS model in simulations of convective cloud systems.

APPROACH

The research is based on the SAMEX large eddy simulation (LES) model with explicit formulation of aerosol and drop size-resolving microphysics. The LES simulations based on observations from field projects will provide datasets necessary for parameterization development. COAMPS simulations based on field projects data will test the parameterization.

WORK COMPLETED

The following tasks have been completed during the 2nd year of the project:

1. In the previous year we developed a new cloud microphysics parameterization for cumulus and boundary layer stratocumulus clouds which can be applied in the cloud resolving models. The parameterization has been now implemented into COAMPS model and is undergoing testing in experiments based on the VAMOS Ocean-Cloud-Atmosphere-Land Study – Regional Experiment (VOCALS-REx) field campaign. The formulation and evaluation of the parameterization based on data from the Rain in Cumulus over the Ocean (RICO) field campaign has been described in a paper published in the Journal of Atmospheric Sciences.

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2. The 2[nd] year work focused on the development of probability distribution function (PDF) formulation in shallow cumulus clouds to allow application of our cloud microphysics parameterization in mesoscale prediction models. The PDF parameterization was developed based on the data from the RICO field campaign. The new parameterization was shown to accurately represent autoconversion and accretion rates on a mesoscale model grid.

RESULTS

1. Formulation of conversion/sedimentation rates in a unified parameterization of shallow cumulus convection and marine boundary layer stratocumulus

A microphysical parameterization for shallow cumulus and boundary layer stratocumulus clouds has been developed. Similar to Khairoutdinov and Kogan (2000) parameterization for stratocumulus clouds, the new parameterization is based on explicit microphysical LES model as a data source and benchmark for comparison. The predictions of the bulk model using the new parameterization were tested in simulations of shallow cumulus and boundary layer stratocumulus clouds; in both cases the new parameterization matched the predictions of the explicit microphysics LES quite accurately. Our results show the importance of the choice of dataset in parameterization development, and the need for it to be balanced by realistic dynamical conditions. The strong sensitivity to representation of rain evaporation is also demonstrated. Accurate formulation of this process, tuned for the case of cumulus convection, has substantially improved precision of rain production. The parameterization formulation and test results are published in the Journal of Atmospheric Sciences. At present time the parameterization has been implemented into COAMPS model and is undergoing testing in experiments based on the VAMOS Ocean-Cloud-Atmosphere-Land Study – Regional Experiment (VOCALS-REx) field campaign.

2. A PDF based microphysics parameterization for shallow cumulus clouds

Previous microphysical parameterizations have been developed for application at a *point in the cloud*, generally taken to be represented by the model grid point. The larger grid spacings used by mesoscale models (~2–20 km) may contain substantial unresolved subgrid-scale (SGS) variability. For nonlinear process rates like autoconversion, using grid-mean values of the microphysical variables can lead to substantial bias in process rates (Pincus and Klein 2000).

Unbiased calculations of microphysical process rates such as autoconversion and accretion in mesoscale NWP models require that SGS variability over the model grid volume be taken into account. This variability can be expressed as probability distribution functions (PDFs) of microphysical variables, and the process rates can be integrated over these PDFs in order to obtain the unbiased grid-averaged process rates. Using dynamically balanced LES results from a case of marine trade shallow cumulus, we develop PDFs of the individual variables q_c, N_c, and q_r, as well as joint PDFs (JPDFs) of pairs of variables (q_c, N_c) and (q_c, q_r); the latter are used to calculate, respectively, autoconversion and accretion in bulk models. Both 1D PDFs and 2D JPDFs are best formulated as functions of their non-dimensional parameters, i.e. normalized using the layer-mean parameter values. Such formulation exhibits weaker height dependence and, hence, allows for more robust parameterization of PDF parameters.

We demonstrate that these 1D PDFs can be approximated using analytical functions and analyze the variation of their parameters in the vertical. The 1D PDFs of droplet concentration N_c can be well

approximated by a Gaussian distribution, which broadens somewhat with height. Cloud water q_c and N_c water mixing ratio distributions are highly skewed and can be represented by lognormal distributions, with relatively weak height dependence. We find that JPDFs of q_c and N_c (inputs to the autoconversion) cannot be represented by a simple product of their individual 1D PDF; only the "exact" JPDF captures correctly the covariation between q_c and N_c. The JPDFs of q_c and q_r (inputs to the accretion rate formula), on the other hand, can be approximated more accurately by the product of the individual 1D PDFs of q_c and q_r.

The process rates calculated using different formulations of the PDFs are compared to the benchmark process rate calculated using the point-by-point variability over the LES grid. Specifically, we calculate the bias in autoconversion and accretion rate. Using the JPDFs that are both height- and time-dependent produces the most accurate values for both autoconversion and accretion (Figure 1a). Approximating the 2D JPDF by using a product of individual 1D PDFs overestimates the autoconversion rates by an order of magnitude (Fig. 1b), whereas neglecting the SGS variability altogether results in a drastic underestimate of the grid-mean autoconversion rate (Fig. 1c). Differences in accretion rate for the different PDF assumptions are smaller compared to autoconversion rate, largely a result of the weaker correlation between variables q_c and q_r and the near-linear dependence on the variables in the accretion rate formula.

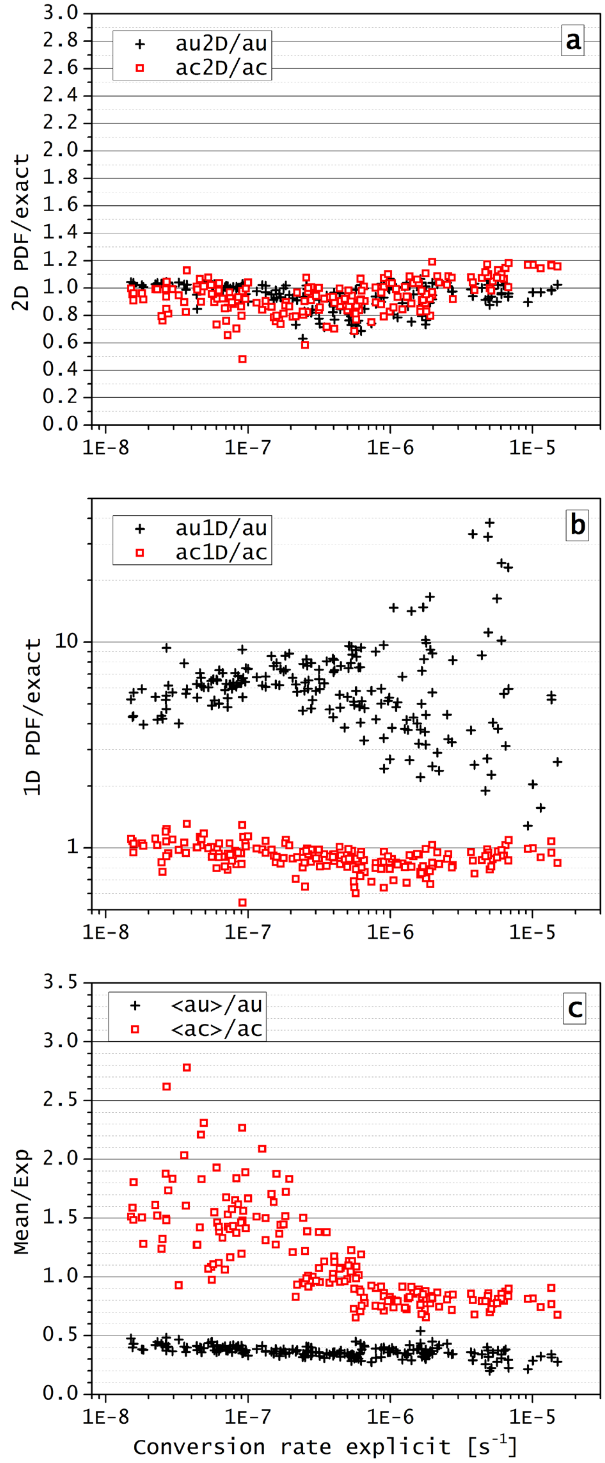

Figure 1. Ratio of various autoconversion (crosses) and accretion (squares) rate approximations to the exact rates. a) rates are approximated by the JPDF; b) by the product of 1D PDFs; c) rates are approximated without the use of PDF based on grid mean values of corresponding parameters. [graph: The joint fully 2D PDF shown in top panel approximate conversion rates most accurately]

Because of the impracticality of using PDFs that are evolving in time during the mesoscale model simulation, we evaluated two additional PDF approximations: a) fixed in time but height dependent; and b) fixed in time and fixed in height. The latter option would be the simplest to implement in mesoscale NWP because it would necessitate only a single JPDF form for each of the two pairs of microphysical variables. Results suggest that use of a single (fixed in time and height) JPDF form for each pair of variables gives an acceptable level of accuracy, especially for autoconversion (Fig 2a). However, much better accuracy is obtained when using height dependent JPDF. We thus recommend using height-dependent JPDFs. In a NWP model one would need to use 6 tables, one for each 400-m-thick layer ranging from cloud base to the highest cloud top. Such computational task can be easily implemented in current NWP models.

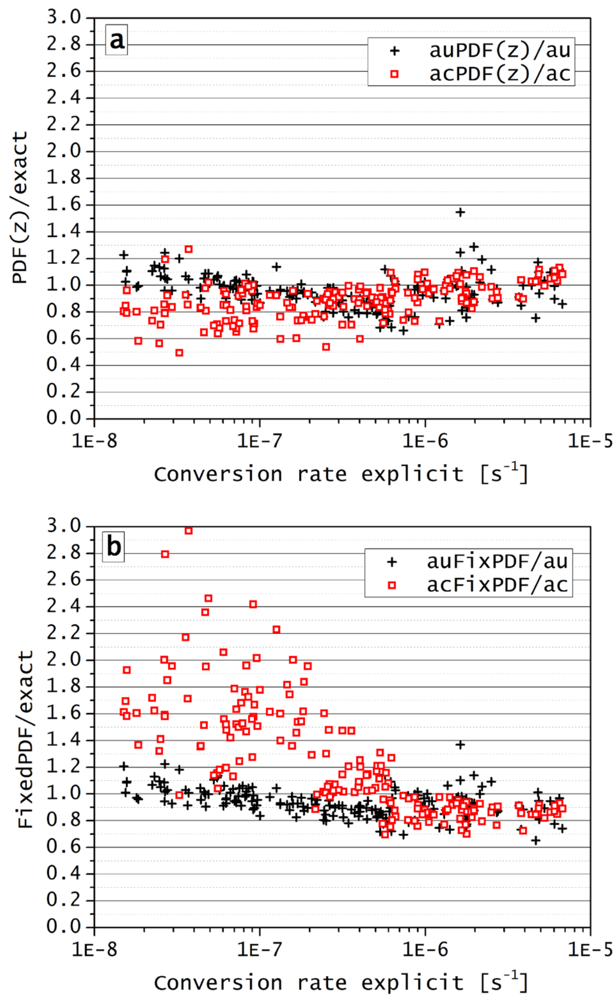

Figure 2. Ratio of various autoconversion (crosses) and accretion (squares) rate approximations to the exact rates. a) rates are approximated by a height dependent, but fixed in time JPDF; b) rates are approximated by a JPDF fixed in time and at a fixed layer corresponding to the middle of the cloud layer [graph: The fixed in time but height dependent 2D JPDFs shown in top panel provide conversion rates as accurate as time evolving JPDFs]

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Khairoutdinov, M. and Y. L. Kogan, 2000: A new cloud physics parameterization for large-eddy simulation models of marine stratocumulus. *Mon. Wea. Rev*, 128, 229-243.

Pincus, R. and S. A. Klein, 2000: Unresolved spatial variability and microphysical process rates in large-scale models. *J. Geophys. Res.,* 105, 27059-27065. doi:10.1029/2000JD900504.

IMPACT

The improved parameterization of the physical processes in shallow convective cloud systems will lead to more accurate numerical weather predictions for Navy operations.

TRANSITIONS

Our results have been published in two refereed scientific papers and reported at the scientific meeting. More presentations are prepared for the upcoming International Conference on Clouds and Precipitation (Boston, 2014).

PUBLICATIONS

Kogan Y. L., 2013: A Cumulus Cloud Microphysics Parameterization for Cloud-Resolving Models. *J. Atmos. Sci.,* **70**, 1423-1436. [published, refereed]

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